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THE IMPORTANCE OF EAR-LIKE COUPLERS IN THE DESIGN OF AN OBJECTIVE TEST FACILITY FOR THE MEASUREMENT OF EARMUFF INSERTION LOSS

by

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SUMMARY

The work described in this report was performed as part of a programme of research aimed at the development of an objective method of earmuff attenuation measurement. Data are presented which show that, for insertion loss measurements, the attenuation spectra produced by an objective method are practically independent of the method of acoustically coupling the measuring microphone to the volume contained by the earmuff. This simplifies the design of the objective method.

This paper was read at the Second International Symposium on Personal Hearing Protection in Industry, Toronto, 14 May 1980.

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1 INTRODUCTION

1.1 General

At RAE there is a continuing interest in the sound attenuation characteristics of flight helmets. Part of the current research programme involves the examination of different methods of measuring attenuation spectra. One possibility under consideration is that of using an objective method or 'artificial head' which could provide a quick and simple means of acquiring attenuation data.

In recent years several 'artificial heads' have been described in the literature. These were usually developed for the quality control of quantity production of earmuffs. Amongst these is a 'head' designed by the present author whilst at the Institute of Sound and Vibration Research of the University of Southampton[1].

This device was designed to be useful as a research and development tool as well as for quality control work and it is now intended that a modified version will be built at RAE to allow work with flight helmets.

The paper which was read at the Second International Symposium on Hearing Protection in Industry, Toronto, May 1980[2], describes one feature of the research programme which preceded the design of the 'artificial head'. The background of the topic and the mechanisms of sound attenuation by earmuffs are briefly discussed and then experiments are described in which the attenuation spectra of earmuffs were measured using a variety of ear-like couplers mounted on a flat plate. The data produced demonstrate that the spectra generated by an objective method are largely independent of the nature of the coupler.

1.2 Measurement of attenuation

Since the development of circumaural protectors many different techniques, both subjective and objective, have been developed to measure the attenuation of these devices. One subjective method in particular, Real Ear Attenuation at Threshold, has been widely adopted as the basis for many national standards. However, it is widely recognised that REAT methods have many disadvantages. For example, the current British Standard, BS5108[3], which incorporates an REAT method, is expensive and time-consuming to perform and capital expenditure is high.

There is, therefore, a need for a low cost, speedy and reliable method of measuring protector attenuation and this must be capable of standardisation. This need may possibly be filled by an objective method.

Such a method would have three main uses. Manufacturers of hearing protectors could well use a speedy and reliable objective method for quality control of quantity production whilst the large scale consumer could use an objective method for acceptance testing. A standard objective method could also be of assistance to research workers and development engineers.

Each of these three applications has similar but significantly different requirements of speed, precision and available expertise. An ideal method could be applied

equally well to each of these areas but if such cannot be achieved then it becomes necessary to examine the effects of any deficiencies on the intended use. This may, in turn, affect the design.

Therefore before beginning to design an objective method it is first necessary to define the limits of what may be achieved. This has been accomplished here partly by an examination of the literature and partly by experimentation.

3 SOUND ATTENUATION MECHANISM

The first step in this work was to examine the mechanisms involved in the attenuation of sound by a circumaural protector. The lower diagram in Fig 1 summarises the situation.

An incident sound wave is largely prevented from reaching the inner ear by interposing a barrier in the form of a roughly hemispherical shell. This shell or cup is pressed against the side of the head by a headband. Sealing the cup to the side of the head is achieved via a cushion attached to the perimeter of the cup.

Obviously this system can never totally eliminate the sound wave before it reaches the ear canal. Firstly, if the sound field is sufficiently intense the ear will receive energy transmitted through the bone and tissue[4,5]. Secondly, there are leaks and resonances of various types in the system.

Simple air leaks occur at the interface between the cushion and the head. The magnitude of these will be a function of the headband, the cushion and the characteristics of the flesh/skin/hair directly beneath the cushion. Resonances occur as the cup vibrates. The amplitude of the energy transmitted in this way will be a function of the spring constants of the air volume inside the cup, of the cushion and of the flesh layer[6-8].

As well as travelling via leaks and resonance sound will also pass into the ear through the material of the cup and the cushion, which both have a finite surface density.

Although the protector mechanisms just described are important, primary interest here lies in the measurement of protector attenuation. Subjective measurement of this quantity is generally performed using an insertion loss technique. In BS5108[3], for example, the subject records a threshold level in the occluded state and this is subtracted from a level recorded in an unoccluded state thus giving a value of attenuation.

An examination of this process is of assistance when designing an objective method. Referring to the upper diagram, of Fig 1, the unoccluded state, the influences exerted on a sound wave *en route* to the ear at a point in the ear canal may be itemised.

The sound wave, emanating from a source, somewhere in the vicinity of the head, may or may not, according to the frequency, be diffracted by the head and shoulders of the subject. After this, the wave may or may not be affected by the resonances of the outer ear and of the ear canal.

Assuming that these effects, if they occur, are independent and linear, which, as we are dealing with logarithmic quantities means additive, then the sound field at that

point may be written as

$$A = f(S + D + O + E + \ldots)$$

where the dots refer to undefined effects occurring after the ear canal and where, for the unoccluded ear,

- S defines the source
- D is the transfer function due to the head and shoulders
- O is the transfer function due to the pinna and concha
- E is the transfer function due to the ear canal.

This is, of course, a crude model of the system but will serve to illustrate some points of interest.

Repeating the process for the occluded ear we have

$$A' = f(S' + D' + X + O' + E' + \ldots)$$

where X is the transfer function due to the earmuff.

Thus, the insertion loss is given by

$$A' - A = f(X)$$

assuming that $S = S'$; $D = D'$; $O = O'$; $E = E'$.

Transmission loss, where both measurements are made in the occluded stage, one measurement under the earmuff and the other outside, is given by

$$A' - f(S) .$$

Examining these assumptions it may be seen that, generally speaking, what is being assumed is that the behaviour of components of the unoccluded system is unaffected by the presence of the circumaural protector.

In the case of the source and the diffraction from the head and shoulders this seems justifiable from the literature. In the case of the outer ear and canal resonance the situation is less clear. However, evidence from the literature together with experimental evidence produced here indicates that these resonances are also largely independent of the presence of the protector.

The work of Rood[9] offers information on both outer ear and canal resonances. Rood[9] performed a series of semi-objective measurements using small microphones placed at the entrance to the ear canal. Both insertion loss and transmission loss techniques were used. The curves shown in Fig 2 represent the results of both types of measurement made on a single protector compared with equivalent data from a BS5108 [9] test.

It may be seen that, over the frequency range of interest there is no significant difference amongst the three curves except in the following respects:

(i) Both semi-objective curves differ, from the subjective curve at low frequencies. It is suggested by Rood[9] that this may be an effect due to physiological noise.

(ii) Both semi-objective curves cross the REAT curve at about 2000 Hz. Rood suggests that this may indicate an effect due to bone conduction.

(iii) Both insertion loss curves differ from the transmission loss curve at 6300 and 8000 Hz. This probably indicates that the disturbance in the pinna and concha resonances caused by the microphone has been eliminated in the insertion loss technique but the information is retained in the transmission loss data.

From the third point and from the agreement between all three curves over the range 2000-6000 Hz it is possible to infer that the ear canal resonances are not much affected by the presence of the protector. However, no direct support for this has been found in the literature.

ATTENUATION MEASUREMENTS

An investigation of the effect of a protector on ear canal resonances has been conducted. Experiments were performed on the Knowles Electronic Manikin for Acoustic Research KEMAR[10], shown in Fig 3, using probe tube techniques developed by Lower[11].

Measurements of sound pressure level were taken at points along the axis of the ear canal of KEMAR with and without a circumaural protector. Single frequencies were used.

The curves in Fig 4 show the variation of SPL along the canal axis at a representative frequency within the range 2000-6000 Hz. This was a difficult experiment to perform and this data cannot be regarded as wholly reliable. However, the results were quite encouraging.

Early experiments using a prototype artificial head[12], shown in Fig 5, have also proved to be interesting in this respect. The head consisted essentially of a thick walled wooden chamber with a circular hole cut into one side. This hole accepted various interchangeable units, two of which are shown in the photograph. The 'head' could be attached to a vibration-isolated tripod which was placed in a diffuse sound field which conformed very nearly to the requirements of BS5108 [3].

Fig 6 shows the basic interchangeable unit which is a machined block of duralumin. The centre is drilled and tapped to accept one of the three simple couplers shown in Fig 7 each of which accepts a condenser microphone cartridge. Measurements of protector insertion loss were made using each coupler, shown in Figs 8 to 10.

The upper curve of Fig 8 shows the spectrum of a signal measured, at a position equivalent to that of the tympanic membrane, on an artificial head which included a replica of an ear canal. The lower curve shows an equivalent spectrum measured when that

ear canal was occluded by a circumaural protector. It may be seen that the ear canal resonance is apparently present in both curves. These data were produced using the 1in × ½in coupler, shown in Fig 7.

The curves in Fig 9 show the attenuation spectra for a single protector determined using each of the ear canals. There were no large differences amongst the three spectra. This suggests that the ear canal resonance information is almost eliminated from the insertion loss spectra in each case. Similar results were observed for other protectors. Fig 10 shows data for a protector with liquid filled cushions where the large increase in attenuation at low frequencies reported by other workers may also be observed.

Further experiments were performed using two commonly available designs of ear-like coupler, the Bruel and Kjaer Artificial Ear Type 4153 and the Zwislocki[13] coupler. The latter including an external ear simulation. Fig 11 shows the arrangements made to mount the Type 4153 in the prototype test facility and Fig 12 shows those for the Zwislocki. The data produced using these devices have been plotted, on the same axes as the data from the 1in × ½in simple coupler, in Fig 13.

The good agreement obtained at middle and high frequencies amongst spectra from couplers of widely disparate designs indicates that, for practical purposes, the method of coupling the measurement microphone to the volume enclosed by the protector is irrelevant.

3 CONCLUSIONS

The evidence presented strongly indicates that the acoustic behaviour of the ear canal and middle ear is, to an extent significant to the measurement of protector attenuation, unaffected by the presence of a circumaural protector covering the outer ear. The strongest support for this view arises from the work dealing with simple couplers which showed that radical changes in the geometry of an ear canal simulation had little effect on measured values of attenuation. Further indications were provided by the work using the BK4153 Type 4153 and Zwislocki couplers which showed that only small differences existed between attenuation spectra measured using different sophisticated couplers. Finally some support was also provided by the work dealing with KEMAR.

If the above argument is accepted it follows that it is not necessary to include a simulation of an ear canal or an ear-like coupler in an objective test facility intended for the measurement of insertion loss.

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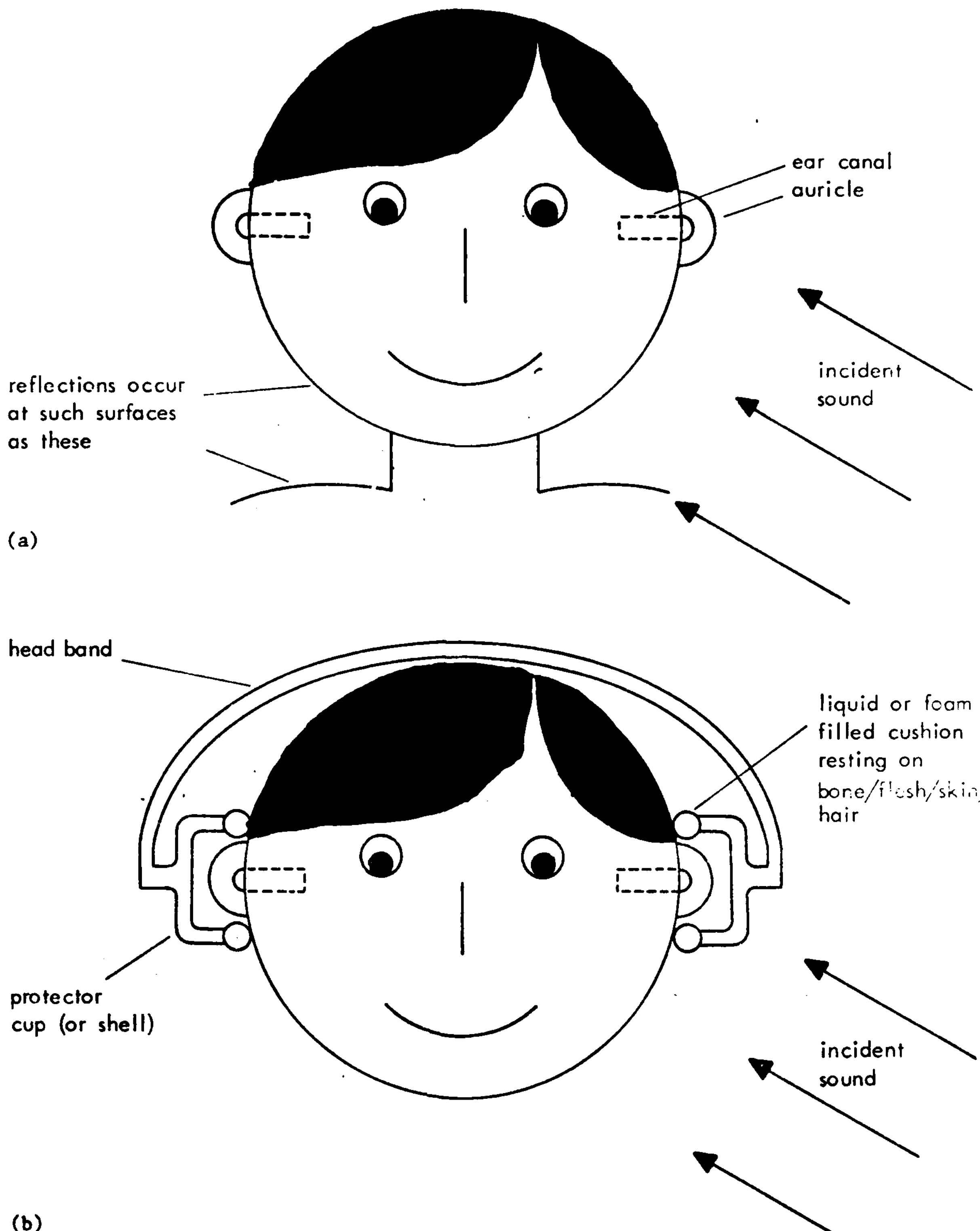

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Fig 1 Illustrating important factors in the measurement of the attenuation of circumaural hearing protectors

Fig 2

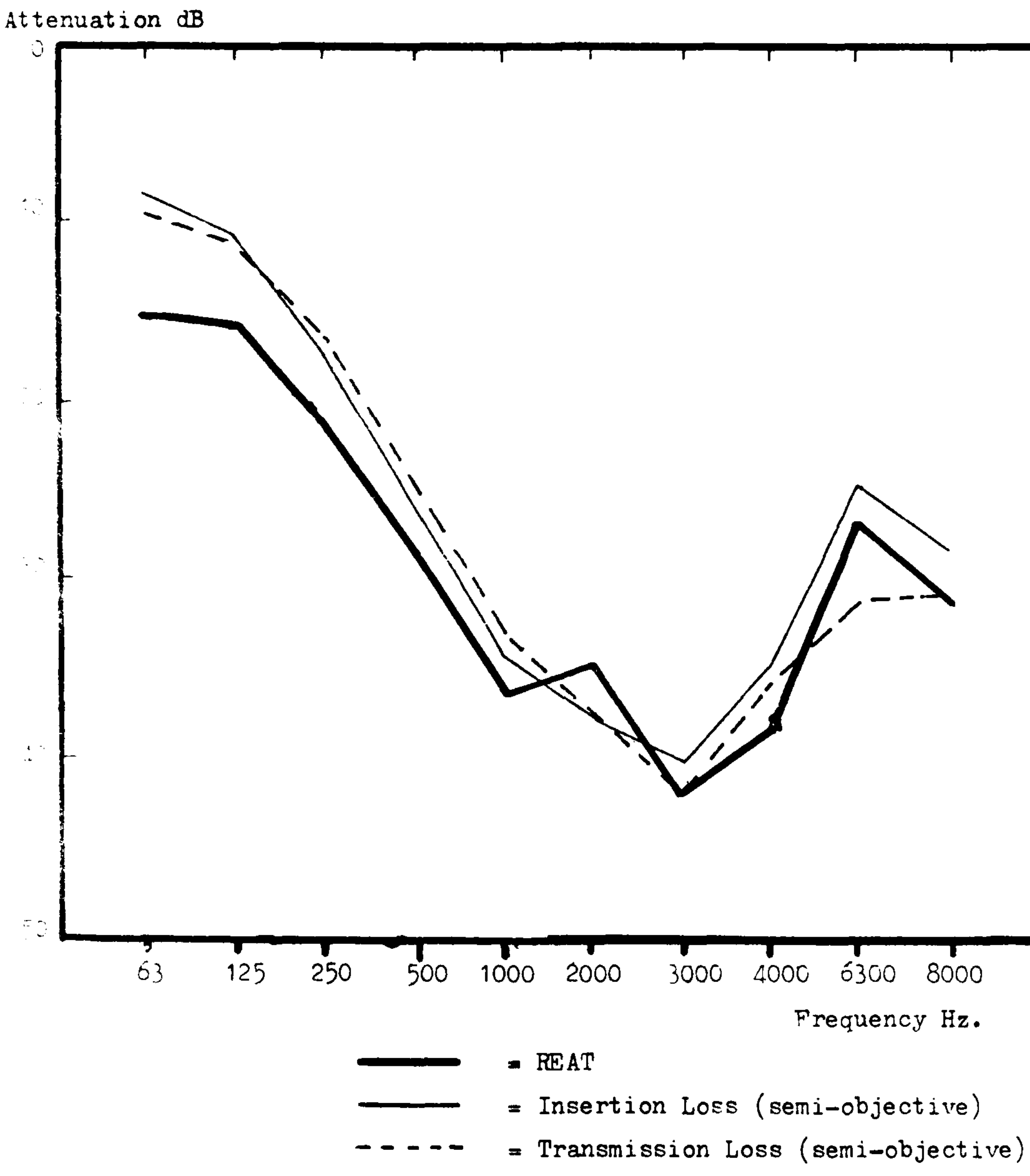

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Fig 2 Comparison of results from three methods of measuring the attenuation of a single protector (after Rood[9], 1980)

Fig 3 The Knowles electronic manikin for acoustic research

Fig 4

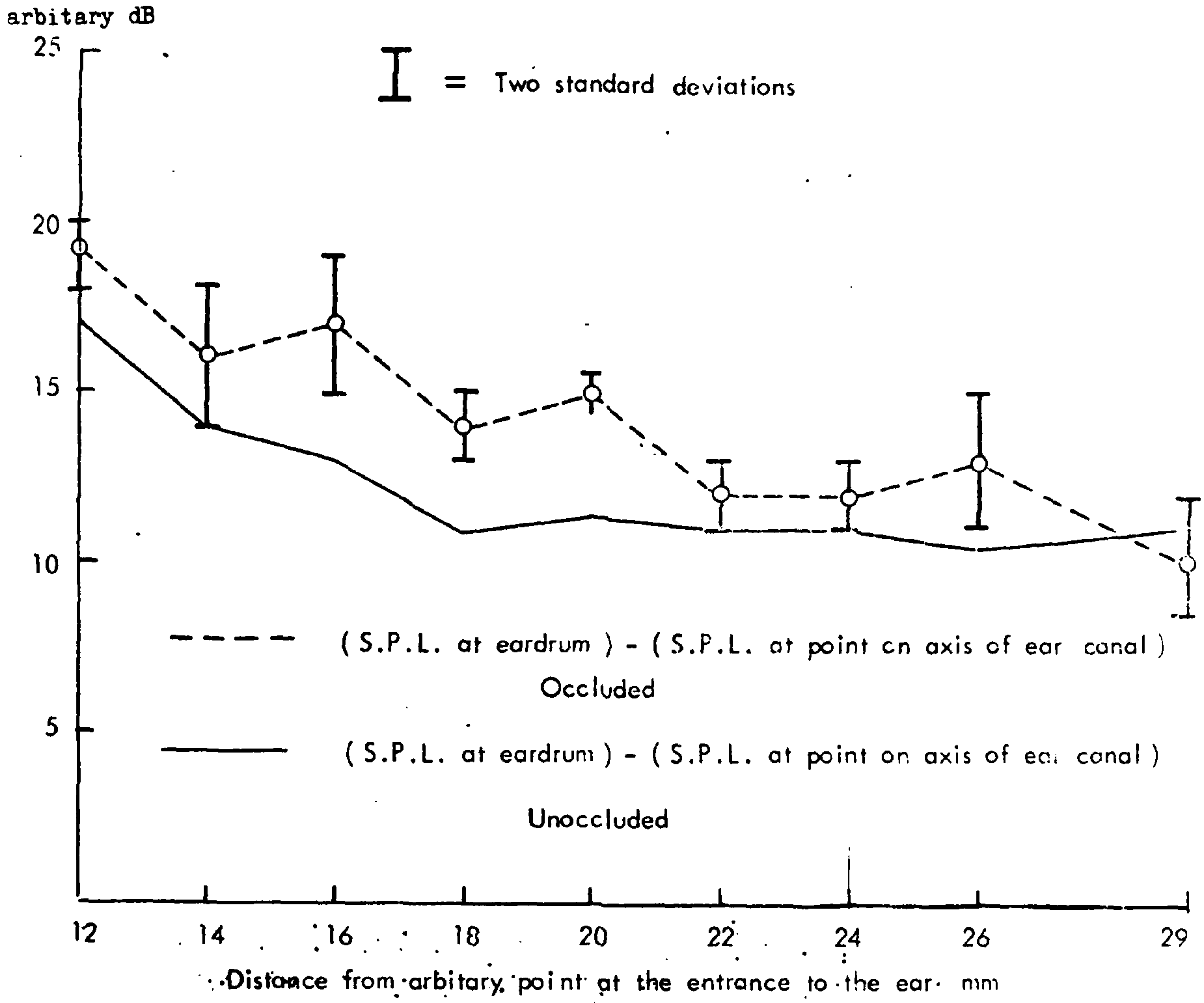

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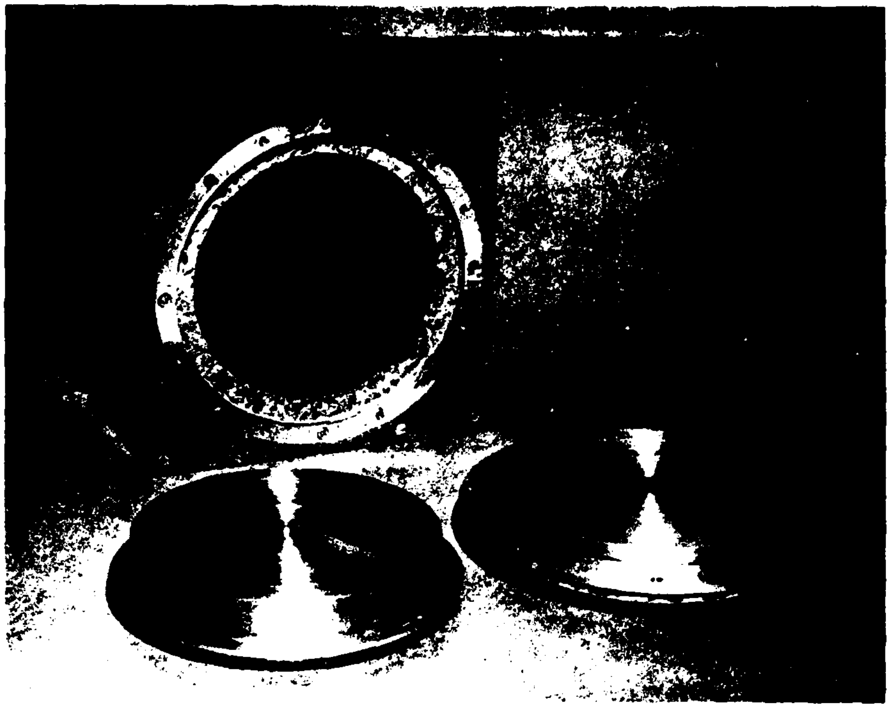
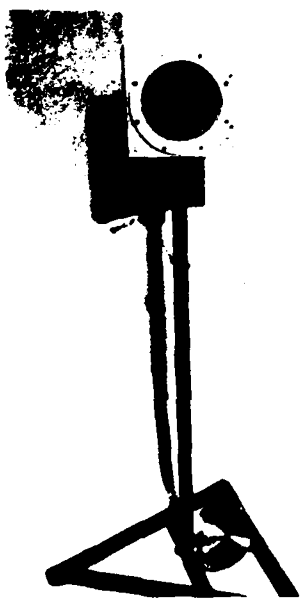
Fig 4 Showing difference in the resonance pattern in Kemar's ear canal between the occluded and unoccluded states



a Artificial head with inserts



b Vibration isolated tripod

Fig 5a&b   Prototype objective test facility

Fig 6

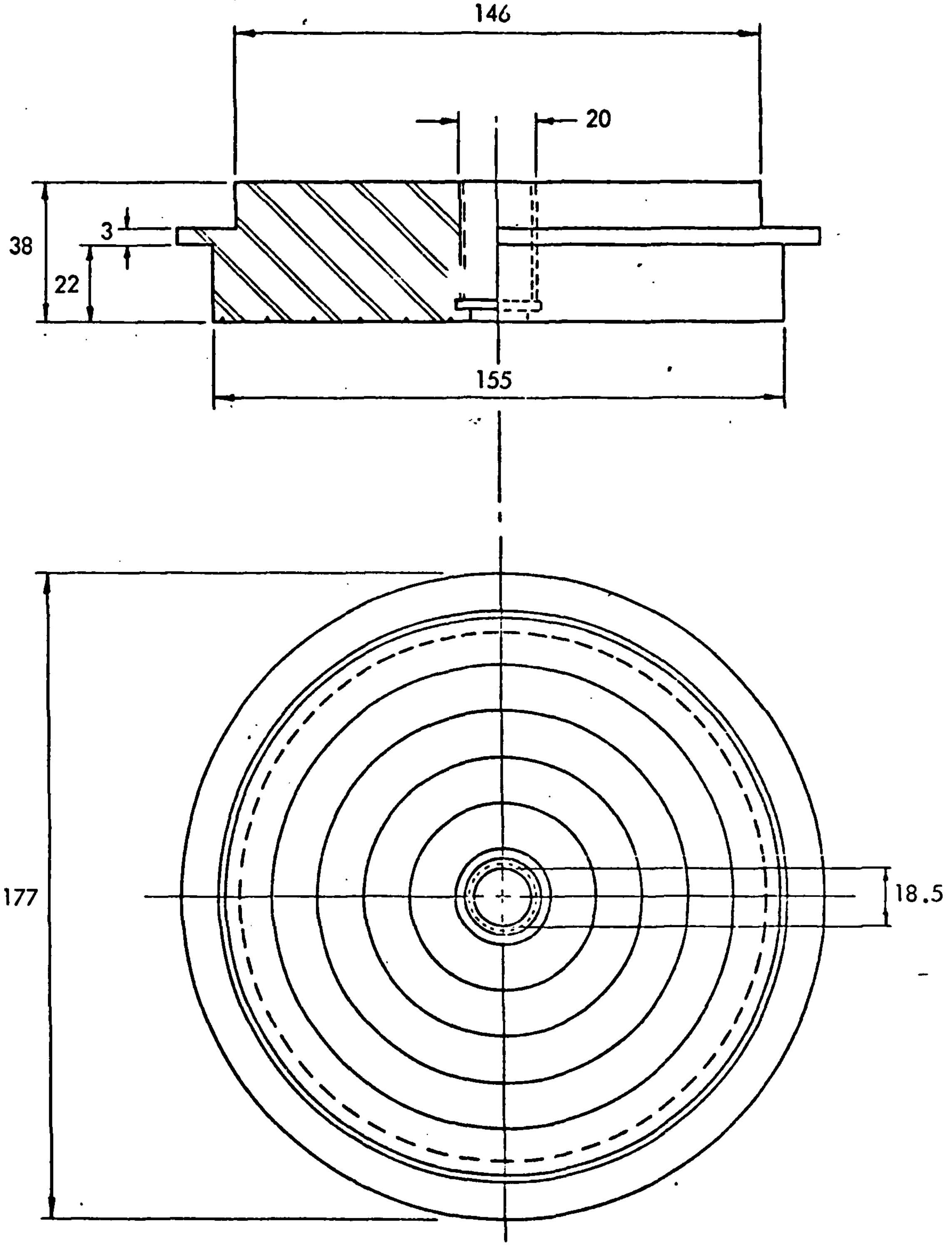


Fig 6 Details of flat plate for test facility

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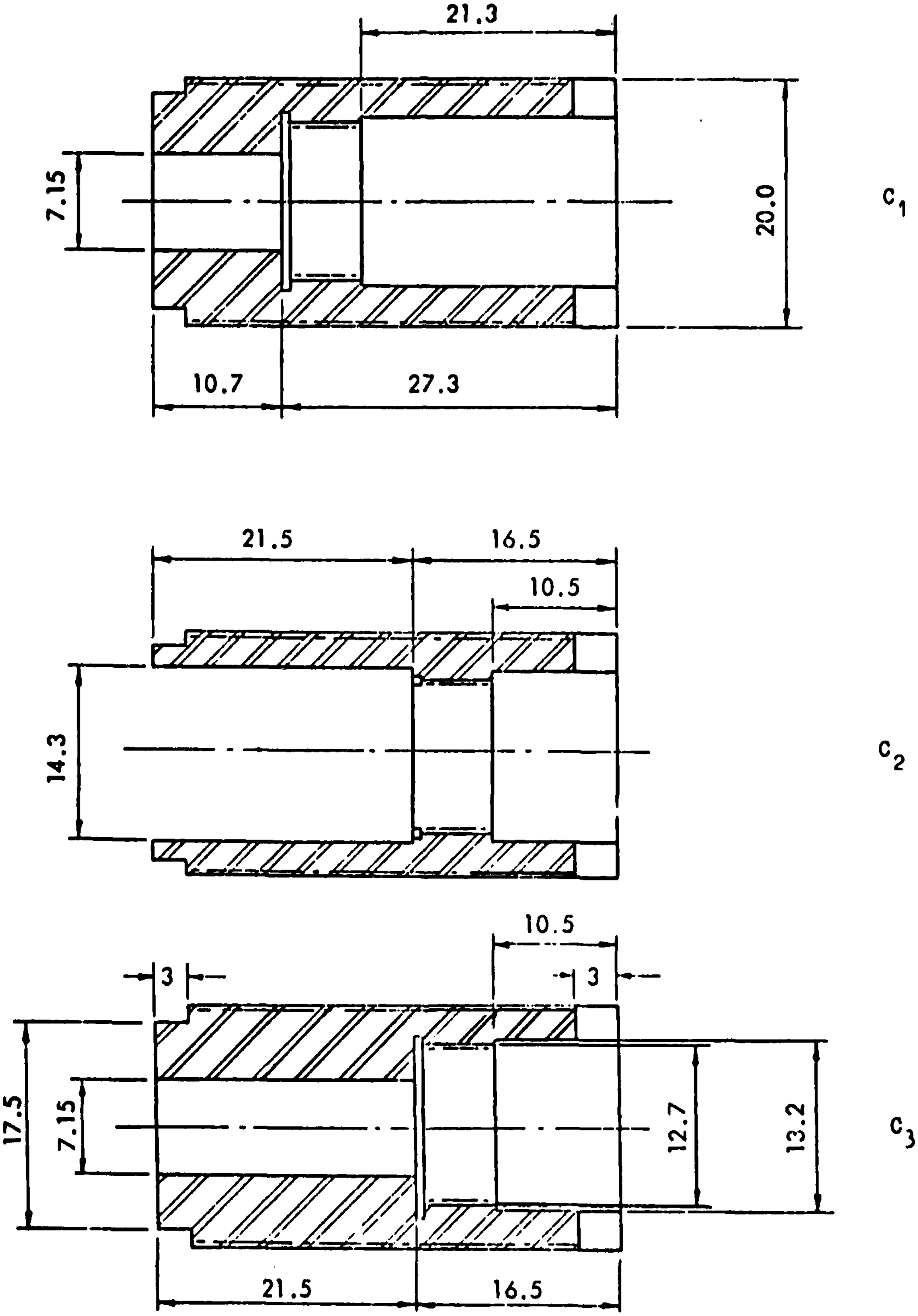

all dimensions in mm.

Fig 7 Showing the three different designs of coupler used on the test facility

Fig 8

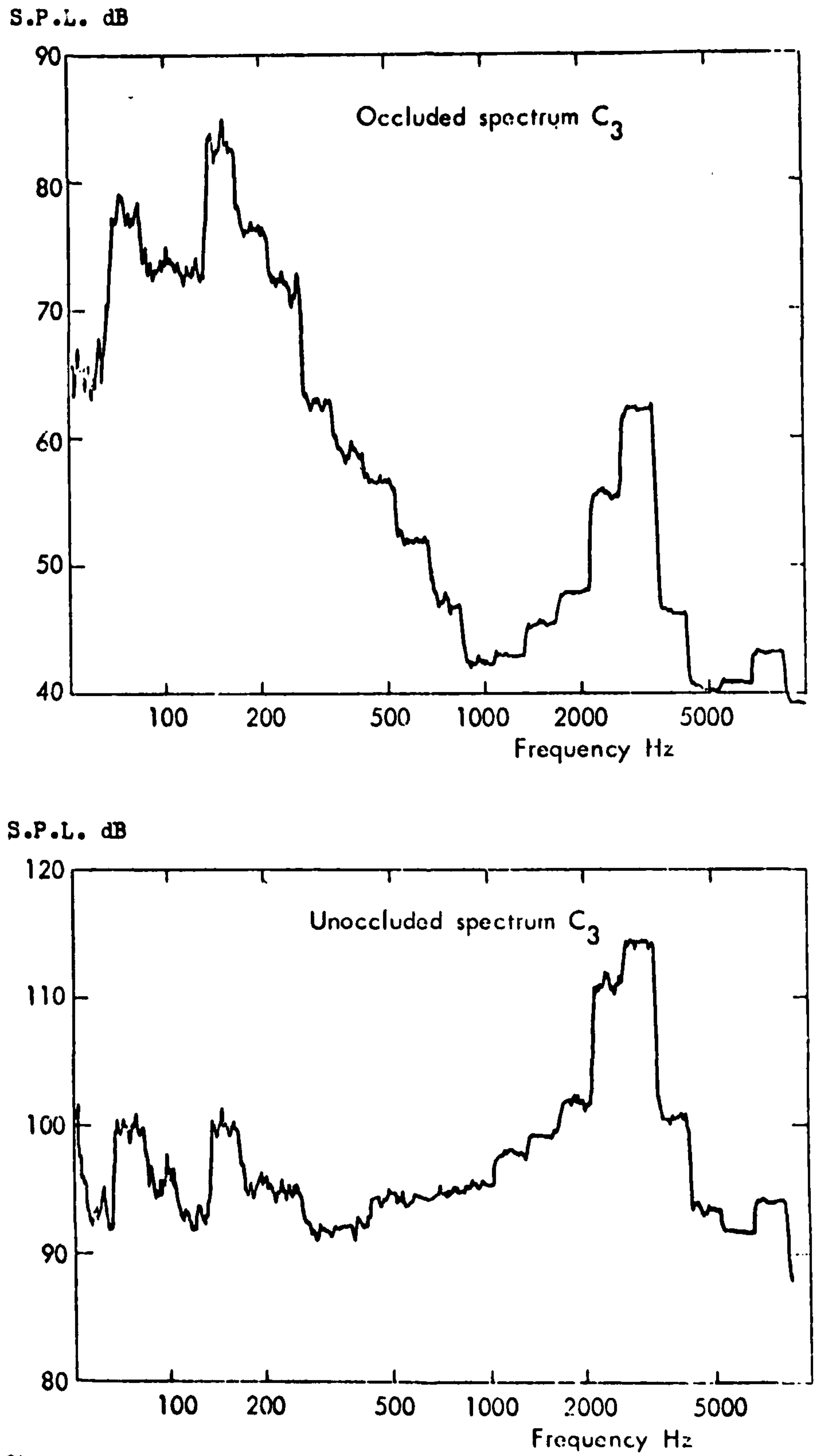

Fig 8 Showing the effect of a hearing protector on the output spectrum of the prototype objective test facility

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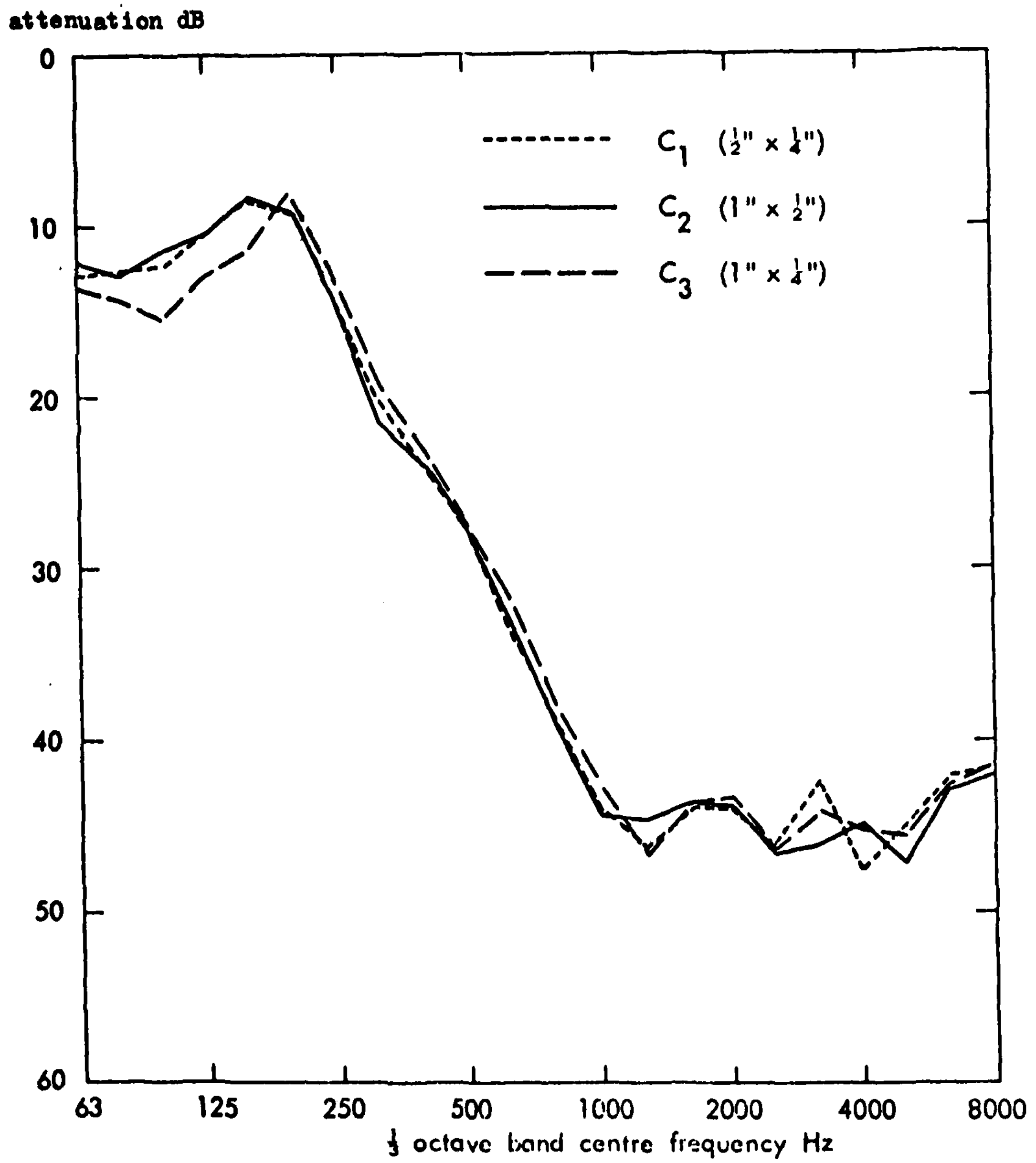

Fig 9 Attenuation spectra measured on test facility using the flat plate with three couplers of different geometries (foam-filled cusions)

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Fig 10

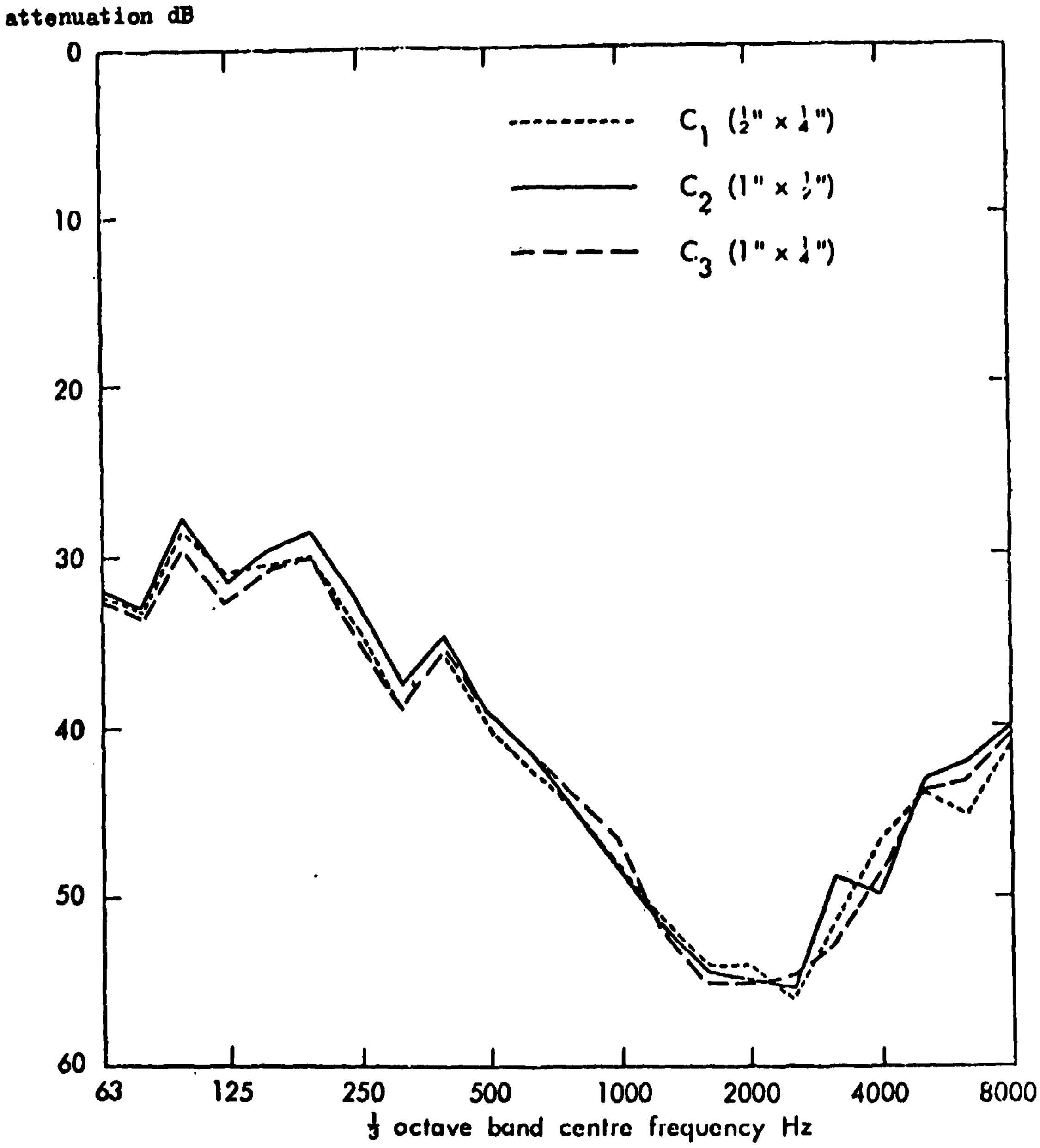

Fig 10 Attenuation spectra measured on test facility using the flat plate with three couplers of different geometries (liquid-filled cushions)

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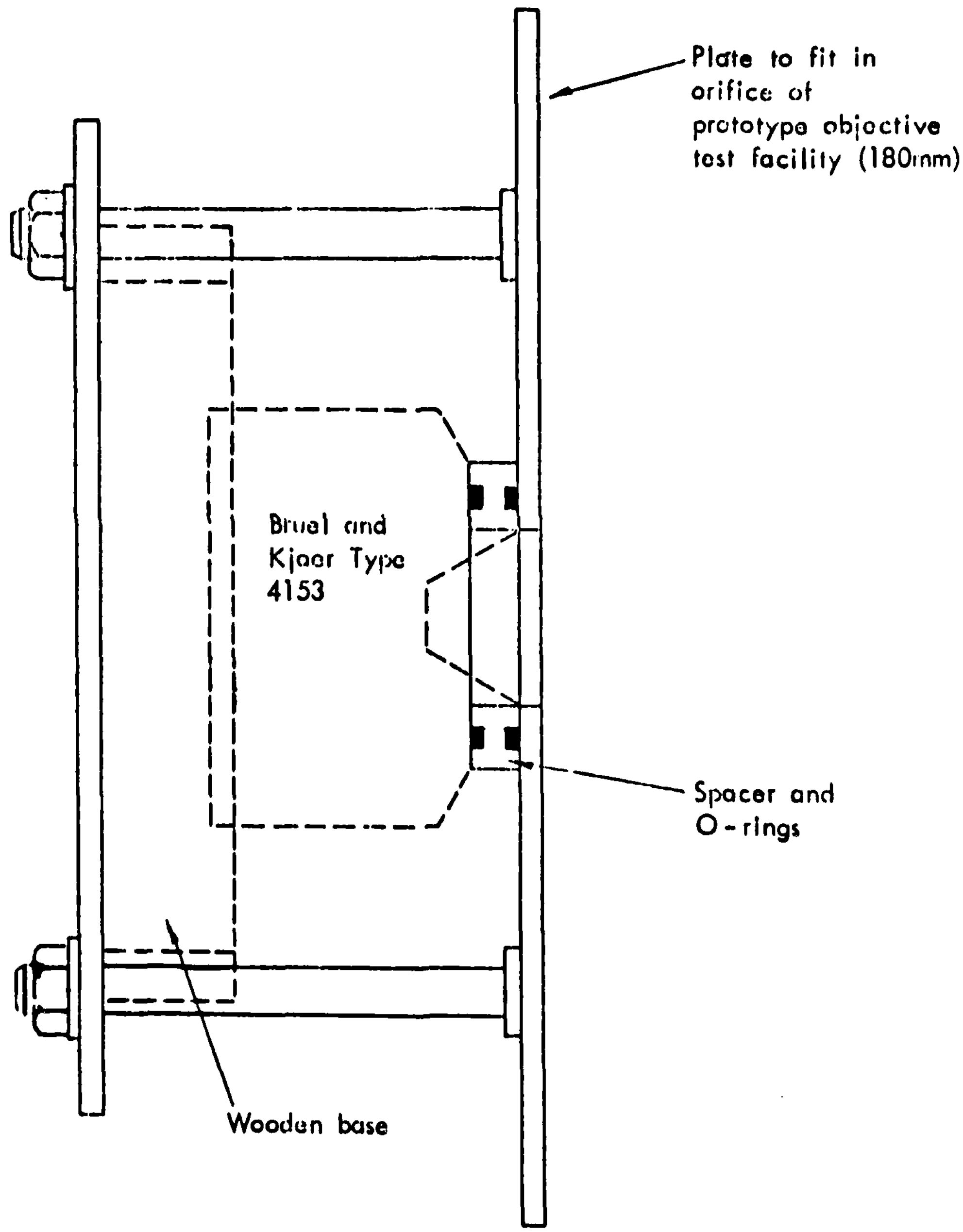

Fig 11 Detail of housing used to mount the Bruel and Kjaer type 4153 artificial ear in the prototype objective test facility

Fig 12

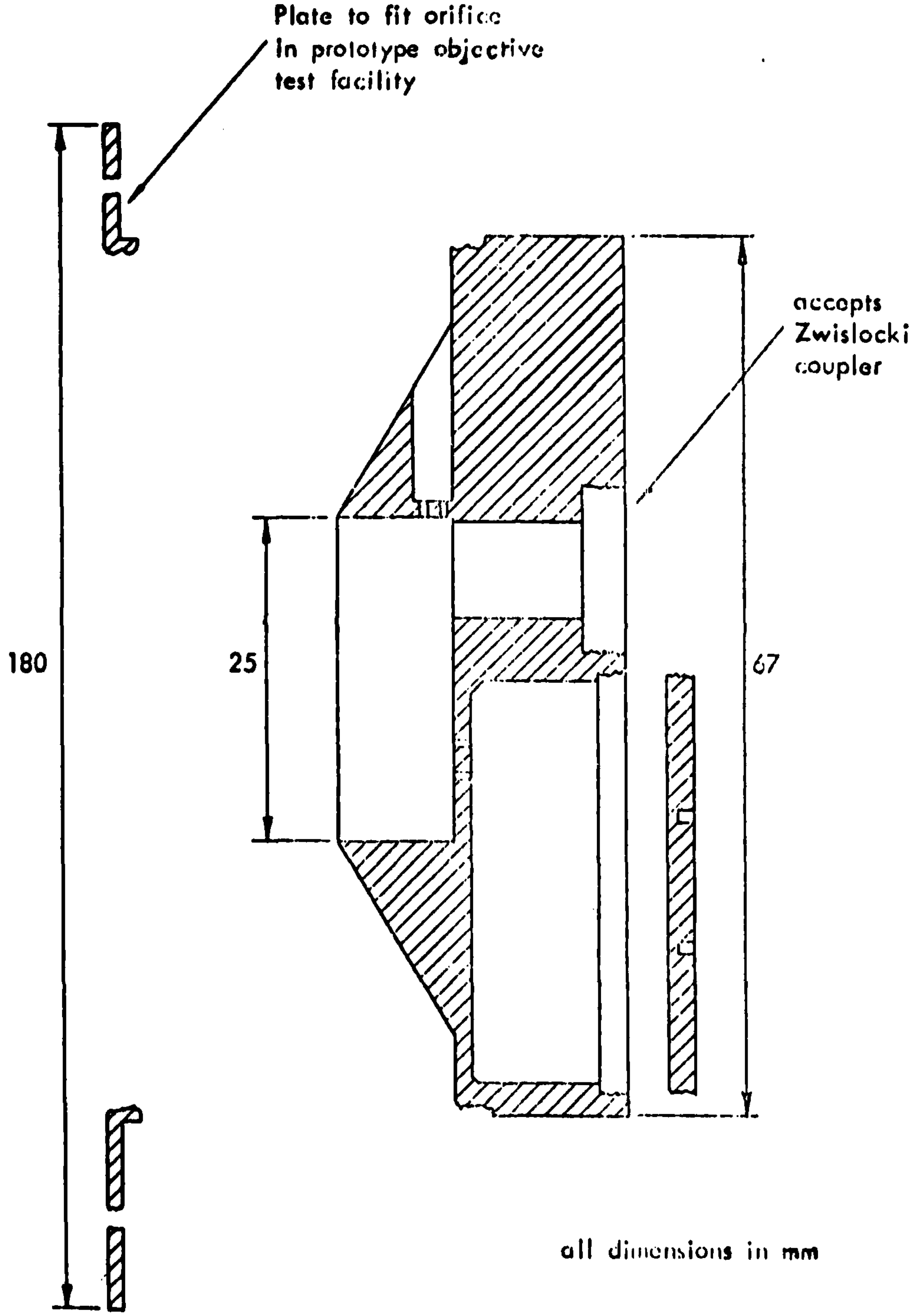

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Fig 12 Detail of Zwislocki coupler with mounting plate

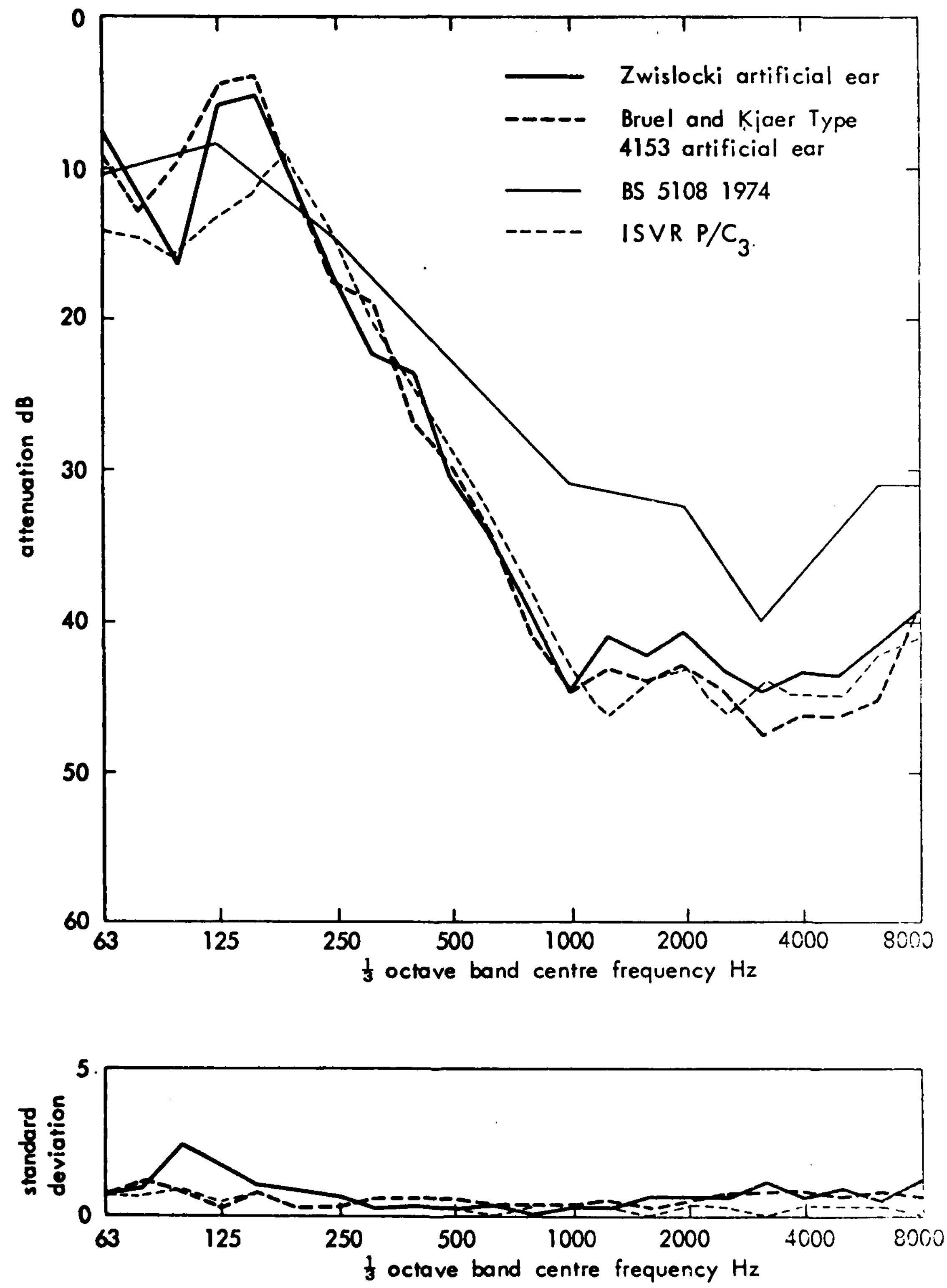

Fig 13 Attenuation spectra measured by four methods (foam-filled cushions)

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17. Abstract

The work described in this report was performed as part of a programme of research aimed at the development of an objective method of earmuff attenuation measurement. Data are presented which show that, for insertion loss measurements, the attenuation spectra produced by an objective method are practically independent of the method of acoustically coupling the measuring microphone to the volume contained by the earmuff. This simplifies the design of the objective method.